

# Focus Issue: Thin-Film Photovoltaic Materials and Devices

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## Introduction

The recent tragic event of the massive oil spill in the Gulf of Mexico reminds us of the challenges of developing sources of energy that are not only abundant and economical but, more importantly, are also as harmless as possible to the environment. Among renewable energy sources, solar photovoltaic (PV) technologies show great potential, as they convert directly sun light into electricity with little impact to the environment, if one excludes those caused during manufacturing, installation, maintenance, and disposal at the end of the product life cycle. Despite these advantages, the share of PV technologies in the energy market has remained small, largely because of the higher cost of energy produced by solar panels compared with that produced by burning fossil fuels such as coal, oil, or natural gas. Hence, the PV industry, which is currently dominated by crystalline and high-purity polycrystalline silicon solar technologies, is making continuous advances to further increase the power conversion efficiency and lower the cost of solar cells and modules.

The first Focus Issue on [Solar Concentrators](#), published in the inaugural issue of *Energy Express* last April, illustrated how power conversion efficiency can be increased by fabricating multi-junction solar cells. Cells with efficiencies higher than 40% have been demonstrated with highly crystalline films of the semiconductors GaInP and GaInAs grown on Ge to be compared with efficiencies of 13 to 19% for silicon modules. However, to reach high performance nearly perfect materials must be grown, which considerably increases their manufacturing costs. That is why these multi-junction cells are combined with solar concentrators that concentrate the light by a factor of 500–1000, reducing the use of semiconductor materials.

This second Focus Issue on [Thin-Film Photovoltaic Materials and Devices](#) deals with a second approach to lower further the cost of energy produced by photovoltaic technologies. In this approach, the focus is less on achieving power conversion efficiencies that exceed those obtained in single-junction crystalline silicon solar cells, but rather on developing new materials and device architectures that lend themselves to streamlined, high-volume manufacturing with greatly reduced semiconductor consumption. In contrast to crystalline solar modules that are assembled from discrete solar cells produced from hundred-micrometer-thick wafers that are cut from ingots, thin-film modules can be manufactured by depositing micrometer-thick (or sub-micrometer in the case of organic semiconductors) thin layers of semiconductors over large areas. Scribing processes (such as laser scribing) are then used to connect the cells in series and parallel to achieve a given set of current and voltage specifications. With these streamlined manufacturing techniques that are essential to further drive down costs, a challenge is to maintain high efficiency and long operational lifetimes. Hence, research on thin-film photovoltaic materials and devices remains vibrant, as further advances in new materials and novel device architectures are essential for the increase of market share of thin-film technologies. Improvements are needed in technologies that are already in the photovoltaic market and are essential for the future commercial success of promising, and potentially disruptive, emerging technologies such as organic photovoltaics.

This second Focus Issue is comprised of original contributions from leading research groups that illustrate both the depth and the breadth of the research conducted on optical materials and devices in a variety of emerging thin-film photovoltaic technologies. To place the potential of this research into context, a paper by [Johanna Schmidtke](#) from Lux Research, Inc. provides an overview of the commercial status of thin-film photovoltaic material and devices and reminds us that the future growth of the photovoltaic market is not just driven by technology alone, but is strongly influenced by public policies and by dynamic trends in the energy market. The recent increase in the market share of commercial thin-film modules such as CdTe and copper indium gallium diselenide (CIGS) speaks for their potential. Schmidtke reminds us that the efficiencies of manufactured modules are still trailing the performance of crystalline silicon photovoltaic modules. Furthermore, many current device geometries sometimes employ materials that cause some environmental concerns (e.g., CdS in CIGS modules). Hence, further research on these technologies is required to enable their future growth.

Newcomers in the commercial photovoltaic market such as organic photovoltaics (OPV) and dye-sensitized solar cells (DSSC) still lag behind their inorganic counterparts, but progress in these technologies is steady. OPV technologies have recently reached efficiencies of 8.1% (Solarmer Energy, Inc.) in laboratory polymer bulk heterojunctions and 7.7% (Heliotech) in molecular multilayer devices with an active area of 1 cm<sup>2</sup>. An example of advances in DSSC technologies is provided in the paper by [Beomjin Yoo and colleagues](#) from KIST Korea. The paper by [Andrew J. Medford and co-workers](#) from RISO in Denmark illustrates how OPV modules can be manufactured using roll-to-roll manufacturing, providing solar technologies with flexible form factors. Despite their great potential, OPV technologies must overcome significant barriers, both in efficiency and lifetime, before they can compete with existing PV technologies. The controlled growth of organic materials can be quite complex. The importance of controlling their morphology in processes that are easily scalable is illustrated in the paper by [Brian E. Lassiter and co-workers](#) from the University of Michigan. Alternatives to organic materials are inks or dispersions of inorganic nanocrystals that lend themselves to manufacturing using printing and moderate processing conditions that can lead to devices with the performance and stability of those based on inorganic materials. The paper by [Vahid A. Akhavan and colleagues](#) from the University of Texas at Austin describes such an approach using CuInSe<sub>2</sub> nanocrystals that are environmentally friendlier than semiconductor nanocrystals used to obtain the highest efficiencies. The paper by [D. Aaron R. Barkhouse and co-workers](#) from the University of Toronto illustrates how detailed optical characterization and modeling techniques can serve to better understand limitations to the performance of these hybrid technologies based on nanocrystals. A paper by [Seungkeun Choi and colleagues](#) from the Georgia Institute of Technology shows that substitutes to indium tin oxide (ITO) such as conducting polymers can be combined with thick metal grid electrodes in large-area organic solar cells.

In my introduction to the inaugural issue of *Energy Express*, I highlighted the power of optical solutions to complex and challenging problems such as renewable and clean energy production. The paper by [Brendan O'Connor and his colleagues](#) at the University of Michigan provides a good example of creative and completely new approaches based on fiber-based architectures that can be used to harvest the sunlight.

I hope that the readers of *Optics Express* and its supplement *Energy Express* will enjoy reading the latest advances described in this Focus Issue and that it will motivate them to publish their latest discoveries in the area of optics for energy in *Energy Express*. I also want to express my sincere gratitude to the contributors who accepted my invitation to contribute an article and who worked around stringent publication deadlines. This second Focus Issue, Thin-Film Photovoltaic Materials and Devices, would not have been possible without the efforts of C. Martijn de Sterke (University of Sydney), Editor-in-Chief of *Optics Express*, and the work of the Associate Editors, reviewers, and the staff coordinating OSA's publications. I want to express my gratitude to all of them.

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